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RESEARCH MEMORANDUM

NOTES ON LOW-LIFT BUFFETING AND WING DROPPING AT MACH NUMBERS NEAR 1

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

NOTES ON LOW-LIFT BUFFETING AND WING DROPPING

AT MACH NUMBERS NEAR 1

By Paul E. Purser

SUMMARY

A study of the available transonic Mach number data on low-lift buffeting, wing dropping, and changes in the angle of zero lift for symmetrical airfoils indicates that these phenomena are allied and are probably the result of shock-induced separation. The study has indicated that there are combinations of airfoil-thickness ratio, aspect ratio, and sweep which may allow flight through the transonic speed range without experiencing buffet or wing drop at low lift.

INTRODUCTION

At transonic speeds, airplanes have encountered buffeting or shaking of the airframe which starts at low lift coefficients (reference 1) rather than only at high lift coefficients near the stall, as has been the case at low speeds. Also at transonic speeds, airplanes have encountered lateral-trim changes, or wing dropping (reference 2). Wing dropping is evidenced to the pilot, as the airplane Mach number is increased, by a sharp increase in the aileron deflection required to hold the wings level or by the rather sudden occurrence of a rate of roll while the ailerons are held fixed. Similar high Mach number wing dropping has been noted in flights of rather simple rocket models (reference 3) in some damping-in-roll investigations. During high-speed wind-tunnel investigations of symmetrical airfoil sections and semispan wings (references 4 and 5) there have been noted changes in lift at zero angle of attack which may be analogous to the rolling moments which cause the wing dropping in flight. These tunnel tests have also shown, through tuft and schlieren observations, the appearance of rough separated flow at low lift coefficients which may be analogous to low-lift buffeting in flight.

The present paper is a discussion of a brief study and comparison made of the data in references 1 to 26 and some unpublished data in an

attempt to obtain a better understanding of these transonic buffeting and wing-dropping phenomena.

SYMBOLS AND DEFINITIONS

M	Mach number
a_n	normal acceleration
C_L	lift coefficient
c_n	section normal-force coefficient
$\frac{pb}{2V}$	wing-tip helix angle, radians
V	velocity along flight path, feet per second
$\Lambda_{c/4}$	angle of sweepback of airfoil quarter-chord line, degrees
α	angle of attack, degrees
p	rate of roll, radians per second
δ_a	aileron deflection, degrees
t	airfoil-section maximum thickness parallel to free-stream direction, feet
c	airfoil-section chord parallel to free-stream direction, feet
A	aspect ratio $\left(\frac{b^2}{S}\right)$
b	airfoil span perpendicular to free-stream direction, feet
S	airfoil area, square feet
$(t/c)_{max}$	maximum airfoil-section thickness ratio measured in streamwise direction (used for wings tapered in thickness ratio)

Buffeting - general shaking of the airframe indicated through sense of touch to pilot or through marked change in width and character of record of normal acceleration-recording device (see fig. 1(a)). M for

zero-lift buffeting is determined from cross plot against M of C_L at which buffet starts (see fig. 1(b)).

Wing dropping - lateral-trim change evidenced by marked increase in aileron deflection required to hold wings level or by change in wing-tip helix angle, (see fig. 1(c)).

DISCUSSION

Data

The data have been obtained from several sources: full-scale flight such as references 1 and 2, rocket-model tests such as references 3, 6, and 7, and wind-tunnel tests such as references 4 and 5. A complete listing of configurations, data, and sources is given in table I.

Wing Dropping

Rocket models.- Some data from reference 3 on wing dropping experienced by rocket models are presented in figure 2 as curves of wing-tip helix angle $\frac{pb}{2V}$ against Mach number M for 6-, 9-, and 12-percent-thick NACA 65A series airfoils having no ailerons, flaps, or camber. Wing dropping is evidenced for the 9- and 12-percent-thick wings by the sudden change in $\frac{pb}{2V}$ at the lower end of the transonic Mach number range. The $\frac{pb}{2V}$ decreases again to a low value before a Mach number of 1 is reached; however, the present discussion is limited to the lower of the two Mach numbers at which the change in $\frac{pb}{2V}$ occurs. The 6-percent-thick wing showed no wing dropping at any Mach number up to the test limit of 1.4. The maximum rate of roll for the 12-percent wing model was about 15 radians per second. Comparable wing dropping for a fighter airplane would be a rate of roll of 1 or 2 radians per second.

The data from figure 2 and other rocket-model data are presented in figure 3 as plots of airfoil-section thickness ratio t/c against Mach number M. The Mach number at which wing dropping occurred is indicated by a vertical arrow on a line drawn at the appropriate thickness ratio. Where no vertical arrow is shown, no wing dropping occurred up to the Mach number indicated by the end of the line or listed in table I. The letters on the arrows and lines refer to the models listed in table I. The boundaries drawn through the arrows in figure 3(a) indicate the combinations of wing thickness ratio and Mach number at or

above which these data indicate low-lift wing dropping to occur for unswept wings. Insufficient data for swept wings are available to establish boundaries (fig. 3(b)).

Although the scatter in figure 3 indicates that the variables considered are not the only ones affecting wing dropping, it is evident that decreases in thickness ratio and increases in sweepback tend to eliminate wing dropping. These facts, combined with the lower values of M and t/c for wing dropping shown for the wedge-type airfoils, which are usually considered to be more susceptible to separation difficulties, indicate that wing dropping is probably a separation-induced phenomenon.

Wind-tunnel tests.- Wind-tunnel tests of symmetrical airfoils at high Mach numbers have shown changes in lift at angles of attack near zero which appear to be analogous to the changes in rolling moment which must have occurred to produce the wing dropping noted with the rocket models. These lift changes are felt to be analogous to wing dropping because, if a wing section is subject to abrupt lift changes induced by separation, only slight dissymmetry in construction or surface finish between the two wing panels would be necessary to cause the lift change to occur on one wing panel first and thus result in an applied rolling moment. Typical high-speed-tunnel data taken from references 13 and 16 are shown in figure 4. Only the lift characteristics of symmetrical airfoils near zero angle of attack are shown in order to prevent confusion between the lift changes felt to be analogous to wing dropping and those associated with transonic changes in camber effectiveness and lift-curve slope. The data in figure 4 show abrupt changes in section lift at high Mach numbers for both 6- and 19-percent-thick NACA 6 series airfoils. The sketches shown in the upper part of figure 4 were drawn from schlieren photographs taken at the Mach number indicated on the curves. The schlierens show asymmetric shock and separation on both airfoils. The separated region and the asymmetry of the shocks are both much wider for the thicker airfoil. Later unpublished schlierens show no such separation or shock-wave oscillations for an NACA 65A003 airfoil.

A plot is presented in figure 5 of thickness ratio against the Mach number at which the lift at angles of attack near zero changed in the tunnel tests. The rocket-model wing-dropping boundary for unswept wings from figure 3 is shown on figure 5 for comparison and a similar boundary has been drawn through the airfoil-section test data. A comparison of these two boundaries and a study of the data in reference 17 indicate that reductions in aspect ratio have a relieving effect on lift changes at angles of attack near zero and, therefore, would probably also tend to relieve the wing-drop tendencies. The fact that the finite-aspect-ratio wind-tunnel points bracket the rocket-model boundary may be fortuitous but does indicate a fairly close relationship between wing dropping in flight and changes in lift at angles of attack near zero in the wind

tunnel. The appearance of separated oscillatory flow in the schlieren at the Mach numbers at which the lift change occurs indicates a probable relationship between wing dropping and low-lift buffeting at transonic speeds.

Buffeting

Low lift.- Buffeting on airplanes in flight has been indicated by various means but the two most usual ones have been pilot feel and normal accelerometers located near the airplane center of gravity. The study reported in reference 1 indicates reasonable correlation between buffet boundaries established in flight by various means. These buffet boundaries are usually presented in the form shown in figure 1(b) as a plot against Mach number of the lift coefficient at and above which buffeting occurs. The Mach number at which the buffet boundary (or a short extrapolation of it) intercepts the $C_L = 0$ axis is considered in this paper as the Mach number for low-lift buffet. Some low-lift buffet data from full-scale flight tests (reference 1 and other sources) and from rocket-model tests are presented in figure 6 as plots of maximum airfoil thickness ratio against Mach number. The Mach number at which low-lift buffet occurs for each airplane or model is indicated by the start of the waviness of the line drawn at the appropriate value of $(t/c)_{max}$. A straight line with no waviness indicates that no buffet occurred at Mach numbers up to that indicated by the end of the line or by the position of the identifying symbols (which refer to table I). Also shown for comparison in figure 6 is the rocket-model wing-drop boundary from figure 3(a). The agreement between the rocket wing-drop boundary, the full-scale flight buffet points, and the one full-scale flight wing-drop point for unswept wings (fig. 6(a)) indicates a probable close relationship of low-lift buffet and wing drop. The data for swept wings (fig. 6(b)) show good agreement between full-scale and rocket flight tests and again indicate that sufficient increase in sweepback or reduction in thickness ratio may eliminate low-lift buffet and wing drop at transonic speeds. The elimination of low-lift buffet by reduction in airfoil-thickness ratio is also indicated by the correlation curve presented in reference 27.

High lift.- The tests reported in references 6 and 7 indicated that, although low-lift buffet was eliminated for thin or highly swept wings, the prestall buffet boundary $\left(\text{near } C_{L_{max}}\right)$ still existed. Typical buffet boundaries from wind-tunnel tuft tests and from full scale and rocket flight-test accelerometer records are presented in figure 7. Comparing figures 7(a) and 7(b) one may see a marked similarity between wind-tunnel and flight indications of the change in character of the buffet boundary when the wing is changed from one on which low-lift buffet exists to one on which low-lift buffet does not exist. Although

the data for nonbuffeting wings in figure 7 are limited to swept wings, the buffet boundary for a thin unswept wing (model R, reference 6) is very similar to that shown in figure 7 for the swept wing, model T, and, thus, indicates the same change in character of the buffet boundary when the wing is changed to one which does not exhibit low-lift buffet. It is probable that the transition between the two types of boundary would be gradual as the sweep was increased or the thickness reduced but sufficient data are not available to indicate this directly.

CONCLUDING REMARKS

A study of the available transonic Mach number data on low-lift buffeting, wing dropping, and changes in the angle of zero lift for symmetrical airfoils indicates that these phenomena are allied and are probably the result of shock-induced separation. The study has indicated that there are combinations of airfoil-thickness ratio, aspect ratio, and sweep which may allow flight through the transonic speed range without experiencing buffet or wing drop at low lift.

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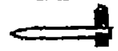
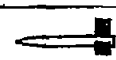
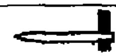
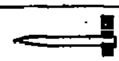
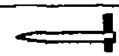
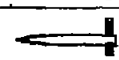
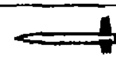
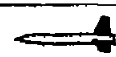
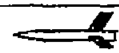
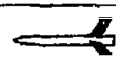
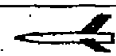
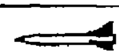
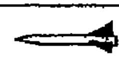
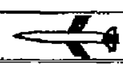
TABLE I

LOW-LIFT BUFFET AND WING-DROP DATA

Symbol	Model or airplane (a)	Aspect ratio A	Sweep, $\Lambda_{c/4}$, (deg)	$(t/c)_{max}$	Airfoil sections: Root	Airfoil sections: Tip	Mach numbers (b): Low-lift buffet	Mach numbers (b): Wing-drop	Reference
A		3.7	0	0.12	NACA 65A012			0.83, 0.835	3
B		3.0	0	0.09	NACA 65A009			0.84, 0.88	3
C		3.7	0	0.09	NACA 65A009			0.885, 0.89	3
D		3.7	0	0.06	NACA 65A006			>1.4	3
E		4.5	0	0.06	NACA 65-006			>1.35	3
F		4.5	0	0.06	6 percent symmetrical double wedge			0.87	3
G		4	5	0.045	4.5 percent modified double wedge			>1.4	Unpublished
H		3	16	0.045	4.5 percent hexagon			>1.4	Unpublished
I		3.7	30	0.09	NACA 65A009			0.93	3
J		4.0	30	0.06	NACA 65A006			>1.15	Unpublished
K		3.7	45	0.09	NACA 65A009			>1.4	3
L		3.7	45	0.06	NACA 65A006			>1.37	3
M		2.31	45	0.06	NACA 65A006			>1.45	Unpublished
N		2.31	45	0.09	3 percent hexagon	9 percent double wedge		0.83, 0.89	3
O		2.7	34	0.075	NACA 65-009 perpendicular to c/4			>1.2	8

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[a]A to U are rocket models, V to 1 are wind-tunnel models, m to z are airplanes.
[b]Blank spaces indicate that no measurements were made.

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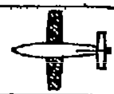
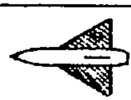
TABLE I

LOW-LIFT BUFFET AND WING-DROP DATA - Continued

Symbol	Model or airplane (a)	Aspect ratio A	Sweep, $\Lambda_{c/4}$, (deg)	$(t/c)_{max}$	Airfoil sections: Root	Airfoil sections: Tip	Mach numbers (b): Low-lift buffet	Mach numbers (b): Wing-drop	Reference
P	 	3.53	34	0.098	NACA 63_1-010 perpendicular to 0.3c	NACA 63_1-012 perpendicular to 0.3c	0.90 0.95	0.95	9 Original records from 10
Q		4	5	0.06	NACA 65-006		>1.5		Original records from 10
R		3	16	0.045	4.5 percent hexagon		>1.35		6
S		3.07	37	0.077	Republic R-4, 40-1710x perpendicular to c/2			>1.78	11
T		3.07	37	0.077	Republic R-4, 40-1710x perpendicular to c/2		>1.2		7
U		2.31	45	0.065	NACA $65_{(06)}$-006.5		>1.28		Original records from 12
V		∞	0	0.06 at 0.7c	6 percent double wedge			0.76	13 and 14
W		∞	0	0.06 at 0.3c	6 percent double wedge			0.75	13 and 14
X		∞	0	0.06 at 0.7c	6 percent circular arc			0.82, 0.83	13 and 14
Y		∞	0	0.06 at 0.5c	6 percent circular arc			0.84, 0.87	13 and 14
Z		∞	0	0.06	NACA 66-006			0.87	13

[a]A to U are rocket models, V to Z are wind-tunnel models, m to x are airplanes.
[b]Blank spaces indicate that no measurements were made.

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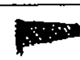
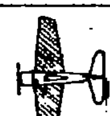
TABLE I

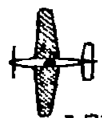
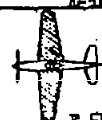
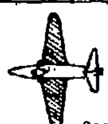
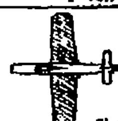
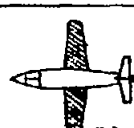
LOW-LIFT BUFFET AND WING-DROP DATA - Continued

Symbol	Model on airplane (a)	Aspect ratio A	Sweep, $\Lambda_{c/4}$, (deg)	$(t/c)_{max}$	Airfoil sections		Mach numbers (b)		Reference
					Root	Tip	Low-lift buffet	Wing-drop	
a		∞	0	0.06	NACA 0006-63			0.86	15
b		∞	0	0.09	NACA 0009-63			0.83	15
c		∞	0	0.12	NACA 0012-63			0.79	15
d		∞	0	0.15	NACA 16-015			0.77	4
e		∞	0	0.19	Modified NACA 65(318)-019			0.71	16
f		∞	0	0.12	NACA 0012			0.80	17
g		9	0	0.12	NACA 0012			0.81	17
h		7	0	0.12	NACA 0012			0.85	17
i		5	0	0.12	NACA 0012			0.85	17
j		3	0	0.12	NACA 0012			0.89	17
k		7.37	~0	0.11	Modified NACA 0012-64 perpendicular to 0.229c		0.875	0.84	5
l		4.31	45	0.078	Modified NACA 0012-64 perpendicular to 0.229c		>0.925	>0.925	5
m	 F6F-1	5.2	~0	0.18	NACA 23018	NACA 23009	0.80		Unpublished
n	 P-39 N-1	5.4	~0	0.15	NACA 0015	NACA 23009	0.78		18

[a]A to U are rocket models, V to l are wind-tunnel models, m to x are airplanes.
[b]Blank spaces indicate that no measurements were made.

TABLE I

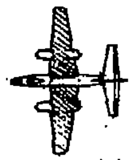
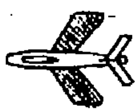
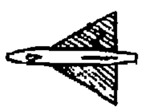
LOW-LIFT BUFFET AND WING-DROP DATA - Continued

Symbol	Model or airplane (a)	Aspect ratio A	Sweep, $\Lambda_{c/4}$, (deg)	$(t/c)_{max}$	Airfoil sections: Root	Airfoil sections: Tip	Mach numbers (b): Low-lift buffet	Mach numbers (b): Wing-drop	Reference
o	 F-51D	5.7	~0	0.144	NACA-NAA Compromise		0.83		19
p	 F-51H	5.8	~0	0.155	NACA 66,2-(1.8)(15.5) a = 0.6	NACA 66,1(1.8)(12.0) a = 0.6	0.82		20
q	 F-80A	6.4	~0	0.13	NACA $65_{(112)}$-213 a = 0.5		0.78		Unpublished
r	 F-84A	5.1	~0	0.12	Republic R-4, 45-1512-.9		0.86		Unpublished
s	 D-558-1	4.2	~0	0.10	NACA 65-110		0.90		21
t	 X-1	6.0	~0	0.10	NACA 65-110		0.90	0.86	22
u		6.0	~0	0.08	NACA 65-108		0.90		Unpublished

[a]A to U are rocket models, V to 1 are wind-tunnel models, m to z are airplanes.
[b]Blank spaces indicate that no measurements were made.

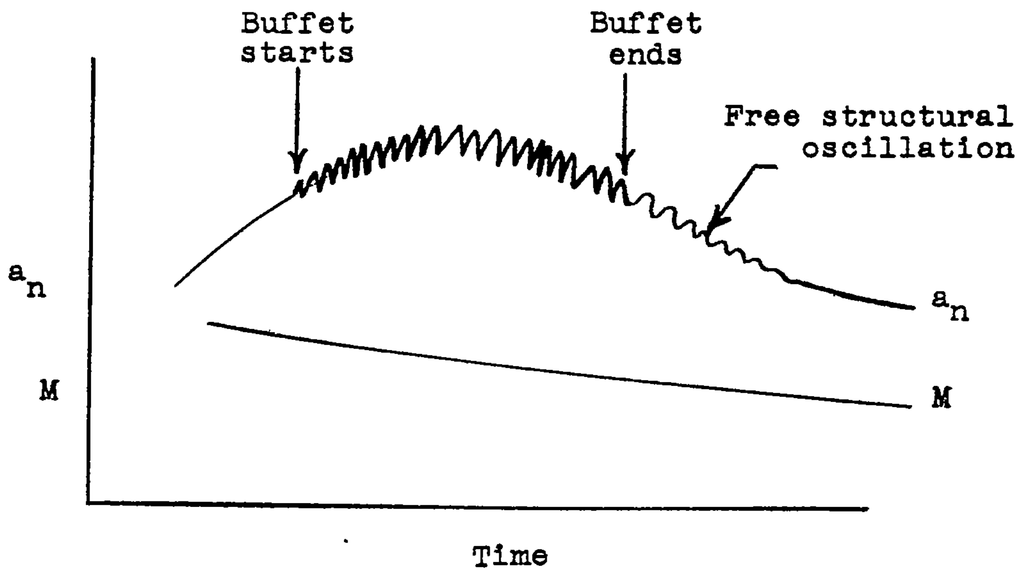
TABLE I

LOW-LIFT BUFFET AND WING-DROP DATA - Concluded

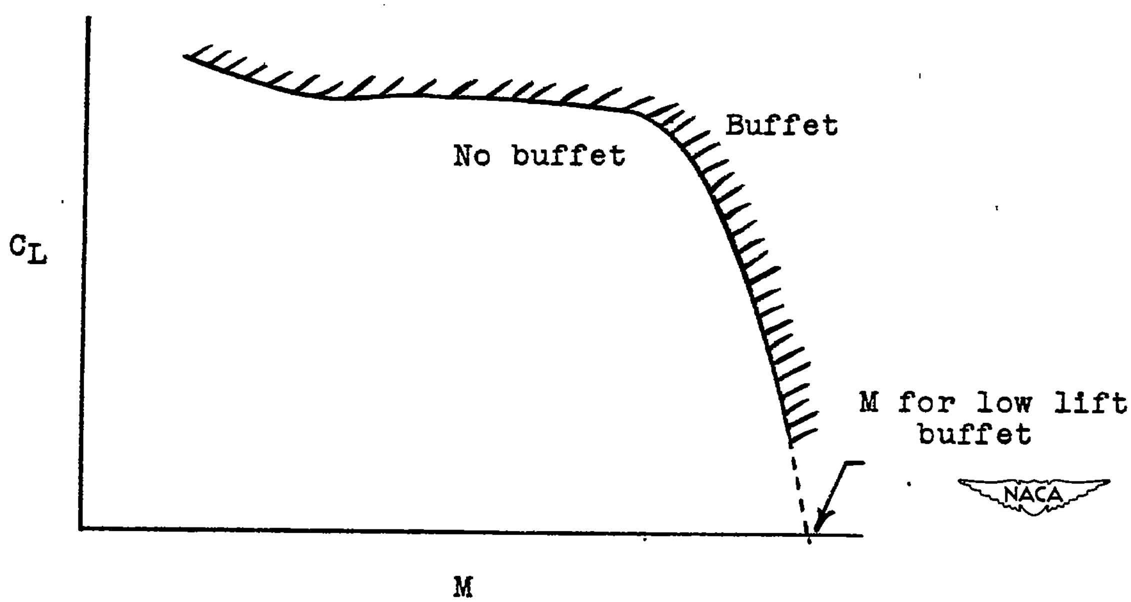
Symbol	Model or airplane (a)	Aspect ratio A	Sweep, $\Lambda_{c/4}$, (deg)	$(t/c)_{max}$	Airfoil sections		Mach numbers (b)		Reference
					Root	Tip	Low-lift buffet	Wing-drop	
v	 B-45	6.8	~0	0.15	NACA 66,2-215	NACA 66,1-212	0.78		23
w	 F-86A	4.8	35	0.093	NACA 0012-64 perpendicular to c/4	NACA 0011-64 perpendicular to c/4	0.98	0.92 to 0.96	2 and unpublished
x	 D-558-2	3.57	34	0.098	NACA 63,-010 perpendicular to 0.3c	NACA 63,-012 perpendicular to 0.3c	0.90		24
y	 XF-91	3.07	37	0.077	Republic R-4, 40-1710x perpendicular to c/2		>1.04	>1.04	25
z	 XF-92A	2.31	45	0.065	NACA 65(06)-006.5		>1.05	>1.05	26

[a]A to U are rocket models, V to 1 are wind-tunnel models, m to z are airplanes.

[b]Blank spaces indicate that no measurements were made.

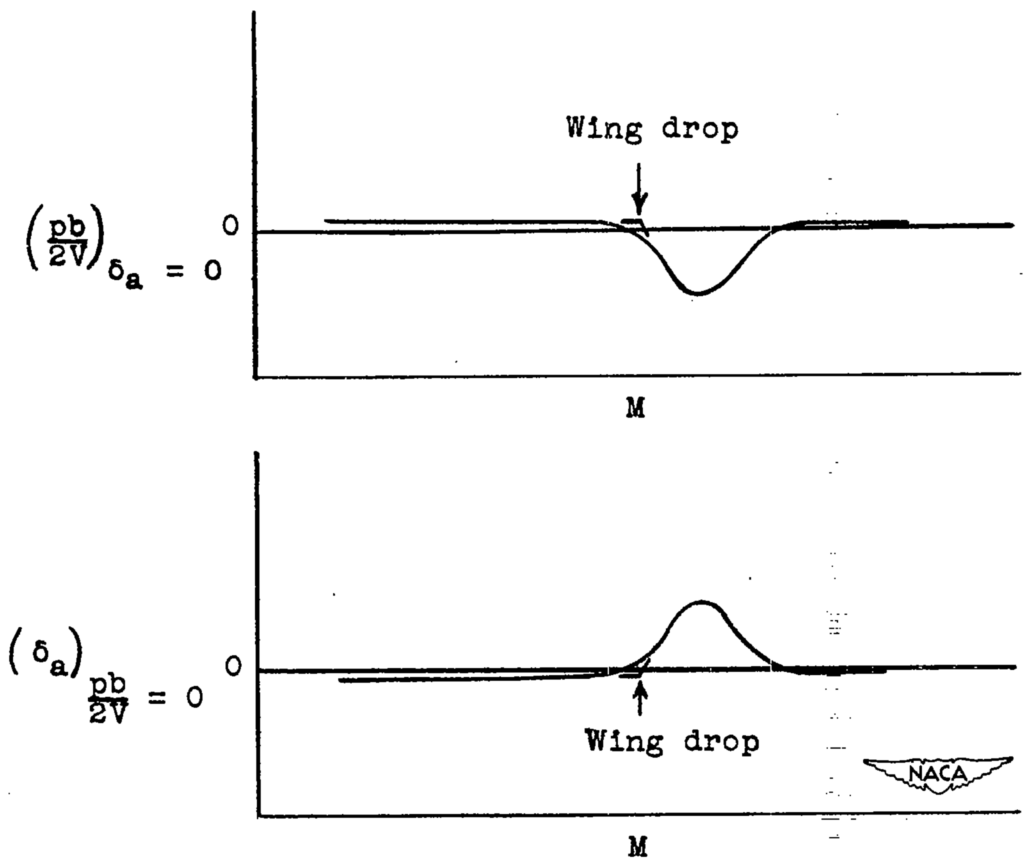


(a) Buffet record.



(b) Buffet boundaries.

Figure 1.- Illustration of terms "buffet" and "wing drop" and Mach numbers at which they occur.



(c) Wing drop.

Figure 1.- Concluded.

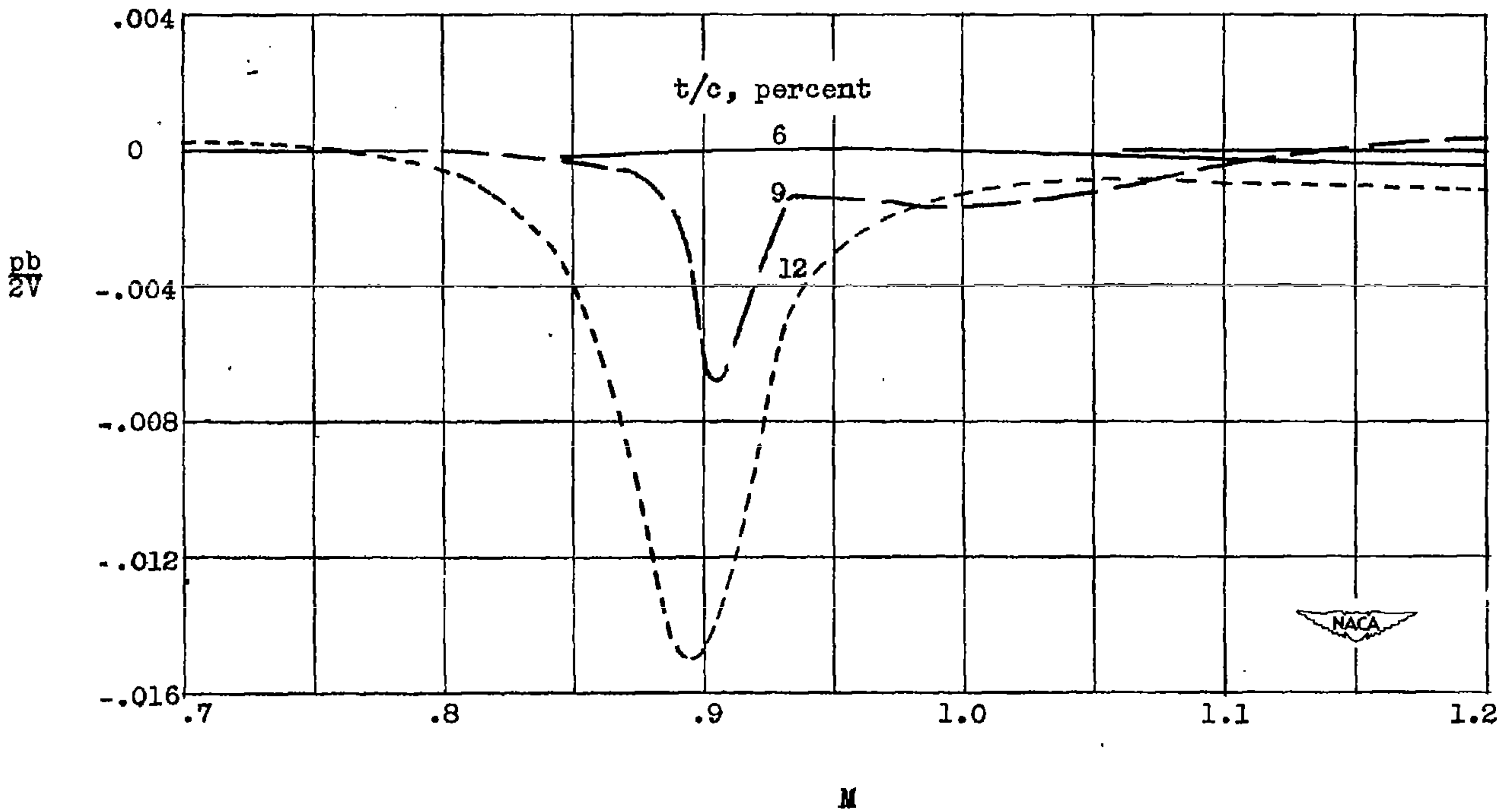
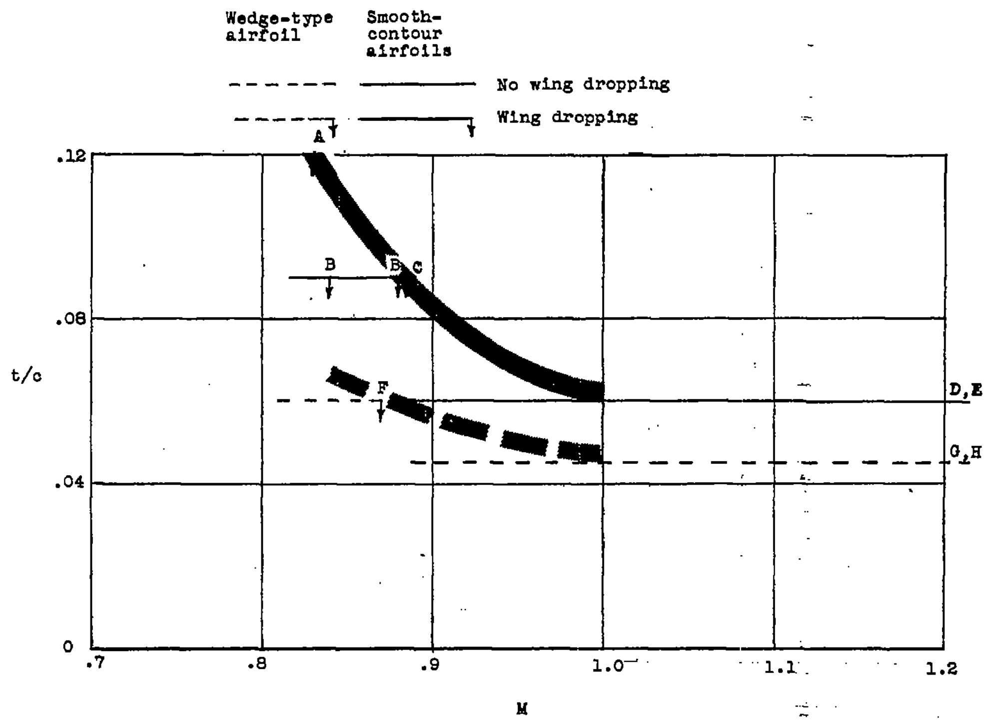
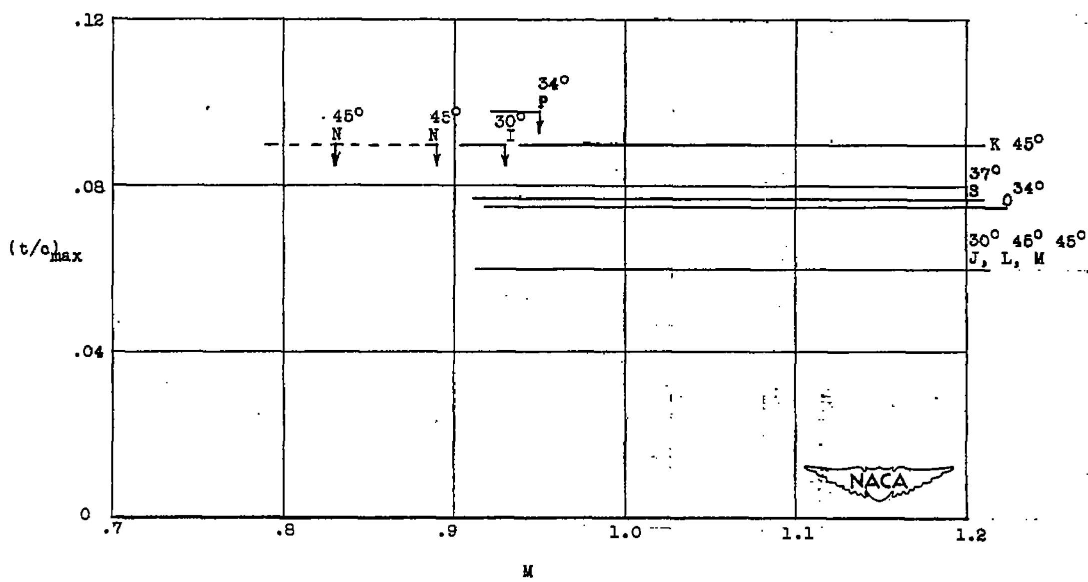


Figure 2.- Typical rocket-model wing-drop data. NACA 65A series airfoil; $A = 3.7$; $\Lambda = 0$. Data from reference 3.



(a) Unswept wings, $\Lambda_{c/4} < 20^{\circ}$.



(b) Swept wings, $\Lambda_{c/4} > 20^{\circ}$.

Figure 3.- Variation with airfoil-thickness ratio of the Mach number for wing dropping as determined from rocket-model tests. Symbols refer to table I.

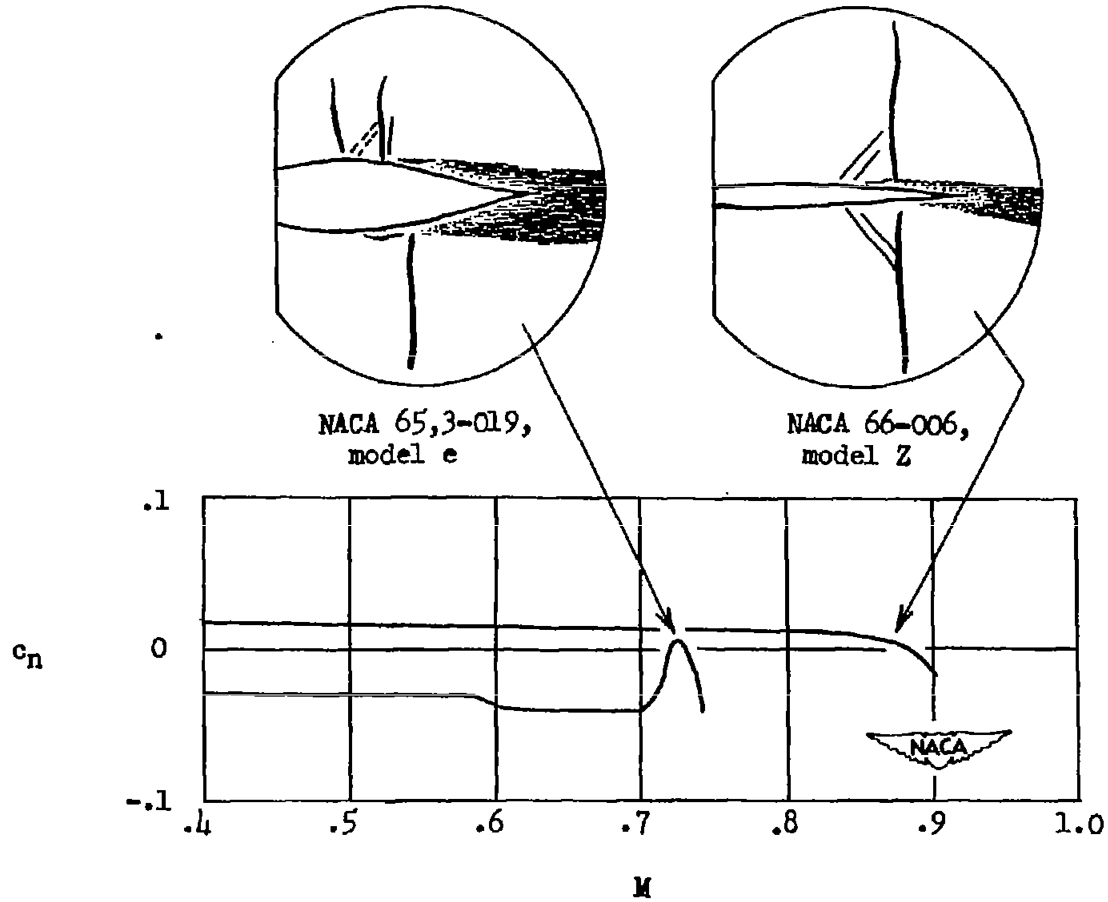


Figure 4.- Typical lift-change data from wind-tunnel tests. NACA 6 series airfoil sections. Data from references 13 and 16.

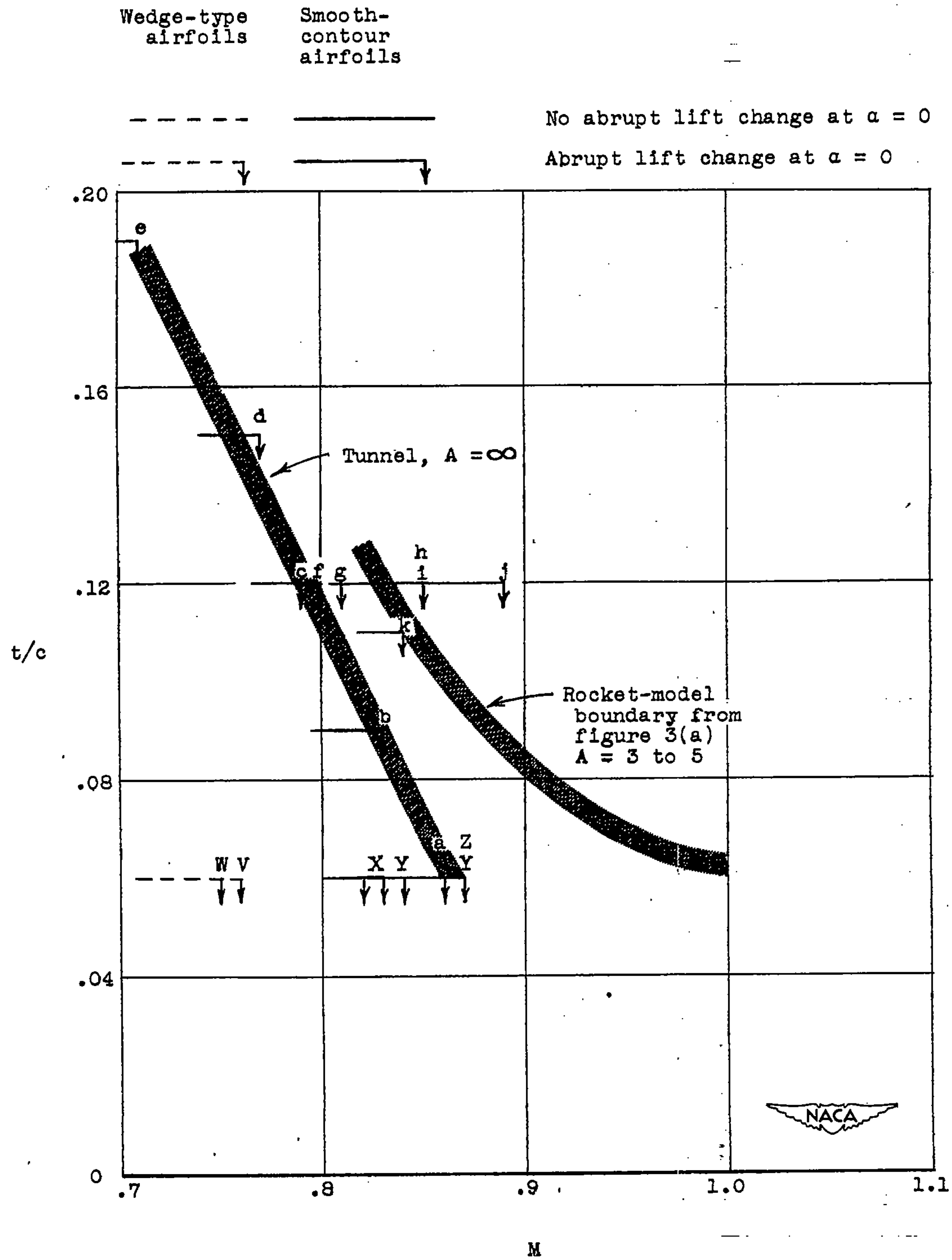
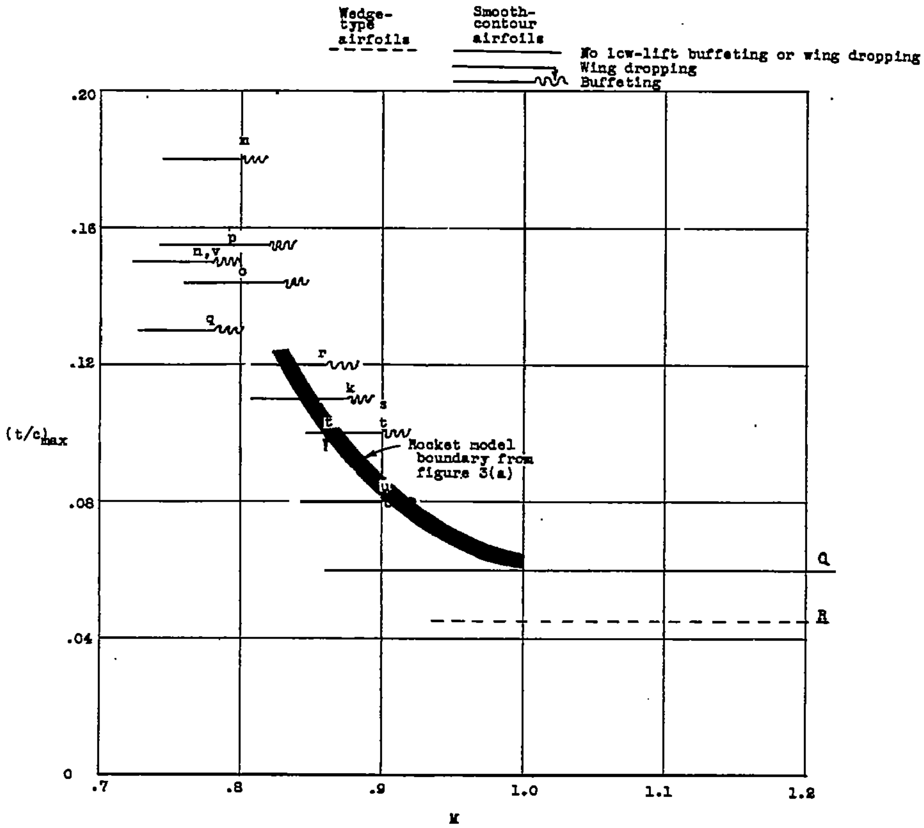
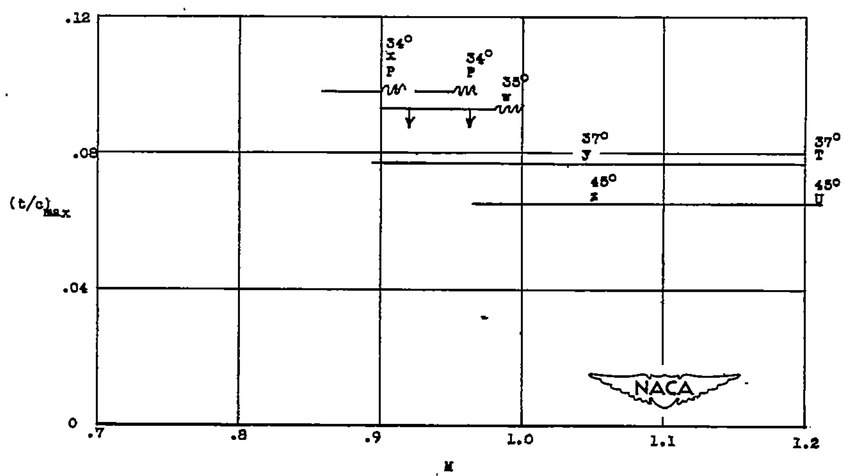


Figure 5.- Variation with airfoil-thickness ratio of the Mach number for change in lift at zero angle of attack from wind-tunnel tests. Symbols refer to table I. Models g through k are finite aspect ratio, all others are airfoil sections.

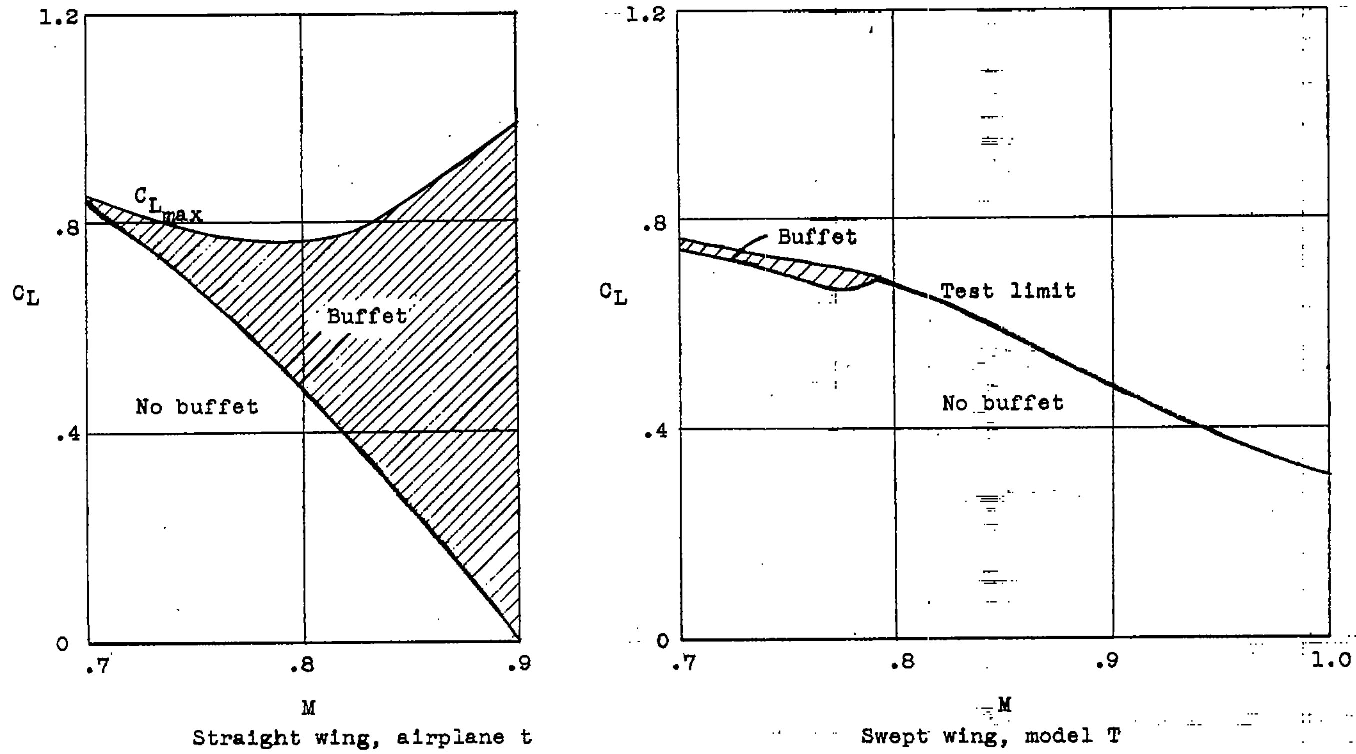


(a) Unswept wings, $\Lambda_{c/4} < 20^{\circ}$.

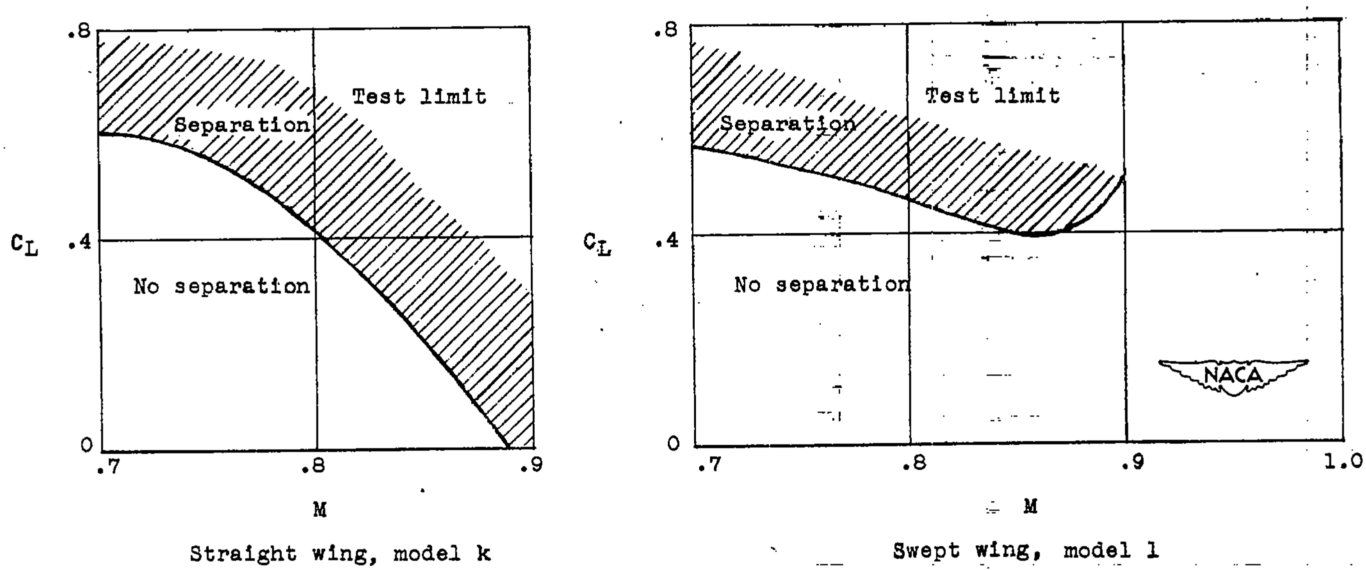


(b) Swept wings, $\Lambda_{c/4} > 20^{\circ}$.

Figure 6.- Variation with airfoil-thickness ratio of the Mach numbers for low-lift buffet and wing drop from full-scale and rocket-model flight tests. Symbols refer to table I.



(a) Flight tests, reference 7 and unpublished data.



(b) Wind-tunnel tuft tests, reference 5.

Figure 7.- Typical lift coefficient Mach number boundaries for buffeting and separation. Model designations refer to table I.

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